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Differential Increases in Excess Mortality in the German Federal States During the COVID-19 Pandemic

Christof Kuhbandner[*] and Matthias Reitzner[†]

Abstract

Background: The present study investigates the influence of COVID-19 on mortality in the sixteen German federal states. To examine this issue, we estimate the burden of the COVID-19 pandemic separately for each federal state by calculating state-specific excess mortalities for the three pandemic years 04/2020-03/2021, 04/2021-03/2022, and 04/2022-03/2023, and explore a number of key state-specific quantities to determine the extent to which these covary with the excess mortality. Among the explored quantities are aspects related to the pandemic (strength of measures, COVID-19 infections and vaccination rates) and aspects unrelated to the pandemic (mean age, gross domestic products, poverty rates, proportions of people in need of care).

Methods: To estimate excess mortality, we compare in each federal state the observed number of all-cause deaths with the number of the statistically expected all-cause deaths. To estimate the expected number of deaths, we use German life tables and longevity trends, and state-specific population tables and state-factors. The results yield for each federal state separate estimates for the expected number of all-cause deaths if there had been no pandemic.

Results: Excess Mortality varied substantially across federal states in each of the pandemic years. In nearly all states, excess mortality was small in the first pandemic year, increased in the second and even more in the third pandemic years. The increase varied substantially across the federal states as well. Regarding the covariations with the explored state-specific quantities, two correlation patterns are noticeable. In the first two years of the pandemic, but not in the third, there was a strong correlation between excess mortality and the number of reported COVID deaths, suggesting that the differences in excess mortality observed earlier in the pandemic are due to differences in the levels of exposure to COVID-19. However, this cannot explain the increase of excess mortality in the second and third pandemic years because the number of COVID-19 deaths decreased instead of increased in almost all federal states. Regarding the increase in excess mortality, an increasingly strong positive correlation with the vaccination rate of a federal state is observed, which reaches a value of $r = 0.85$ in the third pandemic year, indicating that excess mortality increased the stronger the higher the vaccination rate in a federal state was. An analysis of stillbirths showed exactly the same pattern. No other systematic correlation pattern was observed.

Conclusions: Excess mortality during the pandemic varied substantially between federal states, a finding that requires explanation. While the positive correlation of excess mortality with COVID-19 infections and deaths in the the phase of the pandemic without vaccinations suggests an explanation through different levels of exposure to COVID-19, COVID-19 cannot explain the increase in excess mortality after vaccinations began. For the second and third pandemic year a significant positive correlation between the increase of excess mortality and COVID-19 vaccinations is observed, a fact that strongly calls for further investigations on possible negative effects of COVID-19 vaccinations.

Keywords: expected number of deaths, COVID-19, excess mortality in German federal states

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1 Introduction

The development of mortality since the beginning of the COVID-19 pandemic has been intensively examined in previous research. In several countries, a surprising pattern is observed. While mortality increased only marginally beyond the mortality level observed in prepandemic years in 2020, mortality started to increase in the year 2021, reaching extraordinarily high levels in 2022 (e.g., Australian Bureau of Statistics [1]; Kuhbandner and Reitzner [20]; Kye [21]; Scherb and Hayashi [27]). An impressive example is Germany, as shown in a recent paper where the excess mortality observed in Germany was estimated based on the state-of-the-art method of actuarial science, using population tables, life tables, and longevity trends (Kuhbandner and Reitzner [20]; for similar results, see Rößler et al. [26]; Scherb and Hayashi [27]). This is illustrated in Figure 1 which shows the number of excess deaths, estimated with this method, observed in 2020, 2021, and 2022 (for details see the method and result sections below).

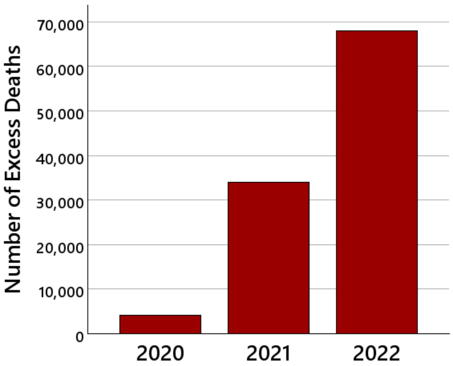

Figure 1: Number of excess deaths in Germany in the years 2020, 2021, and 2022

Given the surprising finding that a significant excess mortality only begins to appear in 2021, which then doubles in the following year 2022, the question arises which factors might be related with this sudden and strong increase in mortality long after the start of the pandemic. One way to approach this question is to examine to what extent the excess mortality observed in the different federal states of Germany varies with different state-specific quantities.

In fact, such a research strategy has already been used in a previous study where it has been examined whether the excess mortality observed in the different German federal states in the second half of 2021 varies with the COVID-19 vaccination rate in a federal state (Thum [32]). According to the results of this study, a significant negative correlation was observed, that is, the higher the vaccination rate in a federal state, the lower the excess mortality, a finding that was interpreted in several media as evidence of the effectiveness of the vaccinations.

However, drawing such a conclusion from this study is problematic due to several reasons. First, the method used in the study to estimate excess mortality does not meet current scientific standards. The number of expected deaths is simply determined by the mean age-standardized death rate across the years 2016-2019. While such an estimation method at least takes into account effects of changes in the size and age profile of the population, effects of historical trends in the development of mortality are ignored. However, as shown in a recent study, since mortality probabilities are still decreasing in Germany from year to year, ignoring mortality trends leads to biased estimates of excess mortality (Reitzner [24]).

Second, the correlation between excess mortality in the second half of 2021 and the vaccination rate was only computed for the vaccination rate at a relatively arbitrary point in time (proportion of the population with at least one first vaccination on September 30, 2021). Thus, it remains to be shown whether the observed correlation at this specific time point also generalizes to other time points and to the rate of second and third vaccinations.

Third, the observed negative correlation between the vaccination rate and excess mortality may actually not reflect a causal effect of the vaccinations. Since there are numerous other variables beyond the vaccination rate in which the different federal states differ, the observed negative correlation between the vaccination rate and excess mortality may actually be driven by third variables. That is, there may be time-stable factors that are independent of vaccination, which lead to excess mortality being generally lower in some federal states, and coincidentally, in the federal states with a generally lower excess mortality rate, more vaccinations were carried out.

In fact, this possibility is mentioned in the study of Thum [32] itself, and an attempt is made to rule it out by examining whether there is also a negative correlation between the vaccination rate in 2021 and excess mortality in 2020. Since the vaccination rate in 2021 cannot account for the excess mortality observed in 2020, finding a negative correlation between the vaccination rate in 2021 and excess mortality in 2020 as well would mean that the negative correlation between vaccination rate and excess mortality observed in 2021 actually reflects the effects of time-stable third variables rather than a causal effect of the vaccinations. While such a research approach is in fact a simple and straightforward method to investigate the existence of possible third variables, the implementation of this method in the study by Thum [32] is questionable. Instead of simply reporting the observed correlation between the vaccination rate in 2021 and the excess mortality in 2020, the author only writes that the same federal state as in 2021 is indeed also at the top of excess mortality in 2020, but that the other federal states would hardly differ from each other in 2020. Thus, it remains unknown whether the vaccination rate correlates not only negatively with excess mortality in the year 2021 but also in the year 2020.

The aim of the present study was to estimate excess mortality in the individual German federal states using scientifically sound methods, and to explore the relationship between excess mortality and several other key state-specific quantities beyond the vaccination rate of a federal state. Excess mortality was estimated based on the state-of-the-art method of actuarial science, using population tables, life tables, and longevity trends (Kuhbandner and Reitzner [20]). The state-specific quantities that were explored were numbers of COVID-19 deaths and infections, vaccination rates, strength of measures taken against COVID-19, gross domestic products as a measure of the wealth of a federal state, poverty rates, mean age, and proportions of people in need of care.

2 Methods

2.1 Mortality Probabilities and Population tables

The standard method to compute the expected number of deaths in insurance mathematics consists of taking the population table containing the number $l_{x,t}$ of living x-year old male, resp. the number $l_{y,t}$ of living y-year old female at the beginning of year t, and multiply it in a suitable way (see (2)) by the male mortality probabilities $q_{x,t}$, respectively female mortality probabilities $q_{y,t}$ for year t which are contained in a life table. The most recent population tables and life tables are published annually by the German Federal Statistical Office.

To estimate the excess mortality in a pandemic situation, one calculates the number of expected deaths if there had been no pandemic. Hence, we use the mortality probabilities $q_{x,2019}$, $q_{y,2019}$ of the last prepandemic 2017/19 life table [8] of the Federal Statistical Office of Germany as the base life table. Because there is a well visible mortality and longevity trend, we use longevity factors $F_m(x), F_f(y)$ which are taken from the DAV 2004R [15] to obtain the mortality probabilities $q_{x,t}$, $q_{y,t}$ for the pandemic years $t = 2020, 2021$ and 2022. This is consistent with our previous investigation [20] concerning the excess mortality for Germany. We refer to [20] for a discussion concerning the use of different life tables, and to [24] for a discussion of the need and the (slightly conservative) choice of longevity factors and the 2017/19 life table. These considerations lead to

German mortality probabilities

$$q_{x,t} = q_{x,2019} e^{-(t-2019)\frac{1}{2}F_m(x)} \quad \text{and} \quad q_{y,t} = q_{y,2019} e^{-(t-2019)\frac{1}{2}F_f(y)} \tag{1}$$

for $t = 2020, 2021$ and 2022.

Before multiplying the population size with the mortality probabilities, one has to take into account the *birthday problem*. Someone dying at age x could have been of age $x-1$ or x at the beginning of the year, depending on his birthday and the precise date of death. As explained in detail in [20] this leads to

$$\mathbb{E}D_{x,t} \;=\; \frac{l_{x-1,t}}{2}\,\frac{q_{x-1,t}+q_{x,t}}{2} + \frac{l_{x,t}}{2}\,\frac{q_{x,t}+q_{x+1,t}}{2}. \tag{2}$$

Analogous formulas lead to $\mathbb{E}D_{y,t}$, and by summation we obtain the total number of expected deaths,

$$\mathbb{E}D_t = \sum_{x=0}^{100} \mathbb{E}D_{x,t} + \sum_{y=0}^{100} \mathbb{E}D_{y,t}.$$

The expected number has to be compared to the observed number of deaths $\hat{d}_t$ in year t.

In our recent paper [20], this method has been used to compute the expected number of deaths $\mathbb{E}D_t$ for the years $t = 2020, 2021$ and 2022 for Germany. Since the publication of this paper, the population table for 2023 was published by the German Federal Statistical Office and the number of deaths for 2022 and partially for 2023 have been updated. This allows to compute the expected number of deaths $\mathbb{E}D_t$ for $t = 2023$ and to state the final results for 2022. Because the number of deaths for 2023 are still preliminary and partially not available, we refrain from including estimates for $\hat{d}_{2023}$. According to [20, Table 3] – with the mentioned updates – this yielded the following Table 1.

Table 1: Expected and observed number of deaths 2020–2023

	2020	2021	2022	2023
expected $\mathbb{E}D_t$	981,557	989,707	998,241	1,004,882
observed $\hat{d}_t$	985,572	1,023,687	1,066,341	

However, looking at calendar years has two major disadvantages. First, since the corona pandemic only had an impact on mortality from around April 2020 onwards, segmentation into calendar years underestimates the influence of the corona pandemic on deaths in 2020 compared to subsequent years, where over the entire year Corona has had effects. Second, during the pandemic, the strongest wave of deaths in Germany was typically observed around the turn of the year. Segmentation in the form of calendar years has the disadvantage that these strong waves of mortality are artificially cut apart and assigned to different year segments, which can lead to distortions.

Fortunately, as shown in our previous paper [9] (see Tables 1 and 2), the expected number of deaths can be distributed onto months using the 'typical' behaviour in the years 2010 – 2019. This opens a possibility to introduce pandemic years, the first P_1 from 04/20 to 03/21, the second P_2 from 04/21 to 03/22, and the third P_3 from 04/22 to 03/23. According to [20, Table 13] – again suitably updated – we obtained the excess mortalities in these pandemic years in Table 2.

Table 2: Expected and observed number of deaths in the pandemic years

	04/20–03/21	04/21–03/22	04/22–03/23
expected $\mathbb{E}D_{P_i}$	981,656	992,127	1,000,102
observed $\hat{d}_{P_i}$	1,004,061	1,019,100	1,077,884

2.2 Excess Mortality in the German Federal States

In this paper we will apply these methods to the 16 German states and compare the occurring excess mortalities, resp. mortality deficits. To this end we start with the German population table $l_{x,t}$ and the state population tables containing $l^{\mathrm{st}_\ell}_{x,t}$ for 16 states st_ℓ, $\ell = 1, \dots 16$, with $x = 0, \dots, 100$, for the years $t = 2009, \dots, 2023$. These tables have been provided by the German Federal Statistical Office, and the Statistical Offices of all German states, except for Rhineland-Palatinate, where the Statistical Office of Rhineland-Palatinate claimed that these numbers for the age groups $x \geq 90$ are too imprecise to be offered. Due to the relation

$$l_{x,t} = \sum_{\ell=1}^{16} l^{\mathrm{st}_\ell}_{x,t}$$

we could reconstruct the missing numbers of the population tables for Rhineland-Palatinate.

For the years $t = 2009, \dots, 2023$ the German Federal Statistical Office publishes the observed monthly number of deaths $\hat{d}^{\mathrm{st}_\ell}_{x,t}$ for each of the 16 states st_ℓ, $\ell = 1, \dots, 16$ for the age groups $[0, 64], [65, 74], [75, 84]$ and the age group ≥ 85.

At a first step one could use the mortality probabilities of the life table 2017/19 of the German Federal Statistical Office for all German states. It turns out that the obtained results do not fit to historical data from the years 2009 – 2019. For nearly all German states, the mortality probabilities deviate systematically from the mortality probabilities for the whole of Germany. Accordingly, when using the German-wide mortality probabilities of the life table 2017/19, the excess mortality in the different federal states would be systematically overestimated or underestimated. This problem is illustrated in Figure 2 below using the two federal states of Baden-Württemberg and Saxony-Anhalt that deviate most strongly from the Germany-wide mortality probabilities of the life table 2017/19.

Hence to adapt the German mortality probabilities $q_{x,t}$, $q_{y,t}$, we introduce *state factors* β^{st_ℓ}, $\ell = 1, \dots, 16$, to obtain state mortality probabilities

$$q^{\mathrm{st}_\ell}_{x,t} = \beta^{\mathrm{st}_\ell} q_{x,t} \quad \text{and} \quad q_{y,t} = \beta^{\mathrm{st}_\ell} q_{y,t}. \tag{3}$$

The state factors β^{st_ℓ} will be chosen to best fit historical data from 2009 to 2019 in the next section.

2.2.1 State Factors Adjusting Mortality Probabilities

In the same way as described above, we compute the expected number $\mathbb{E}D^{\mathrm{st}_\ell}_{x,t}$ of x year old male deaths in state st_ℓ by

$$\begin{aligned} \mathbb{E}D^{\mathrm{st}_\ell}_{x,t} &= \frac{l^{\mathrm{st}_\ell}_{x-1,t}}{2} \frac{q^{\mathrm{st}_\ell}_{x-1,t} + q^{\mathrm{st}_\ell}_{x,t}}{2} + \frac{l^{\mathrm{st}_\ell}_{x,t}}{2} \frac{q^{\mathrm{st}_\ell}_{x,t} + q^{\mathrm{st}_\ell}_{x+1,t}}{2} \\ &= \beta^{\mathrm{st}_\ell} \left(\frac{l^{\mathrm{st}_\ell}_{x-1,t}}{2} \frac{q_{x-1,t} + q_{x,t}}{2} + \frac{l^{\mathrm{st}_\ell}_{x,t}}{2} \frac{q_{x,t} + q_{x+1,t}}{2} \right) \end{aligned} \tag{4}$$

because of (3), where the mortality probabilities are defined in (1) and the state factors β^{st_ℓ} are to be defined. (For $x = 0$ we set $q^{\mathrm{st}_\ell}_{-1,t} = q^{\mathrm{st}_\ell}_{0,t}$, and $l^{\mathrm{st}_\ell}_{-1,t} = l^{\mathrm{st}_\ell}_{0,t+1}$ if available, and $l^{\mathrm{st}_\ell}_{-1,t} = l^{\mathrm{st}_\ell}_{0,t}$ else.)

Analogous formulas lead to $\mathbb{E}D^{\mathrm{st}_\ell}_{y,t}$. Finally summation gives the total expected number of deaths

$$\mathbb{E}D^{\mathrm{st}_\ell}_t = \sum_{x=0}^{100} \mathbb{E}D^{\mathrm{st}_\ell}_{x,t} + \sum_{y=0}^{100} \mathbb{E}D^{\mathrm{st}_\ell}_{y,t} = \beta^{\mathrm{st}_\ell} \triangle^{\mathrm{st}_\ell}_t$$

in year t. If the year t is a leap year, we add an additional day by multiplying the result by $\frac{366}{365}$.

Observe that the numbers $\triangle^{\mathrm{st}_\ell}_t$ are given by the life table 2017/19 of the German Federal Statistical Office and by the population tables $l^{\mathrm{st}_\ell}_{x,t}$, $l^{\mathrm{st}_\ell}_{y,t}$. We define the state factors β^{st_ℓ} as the solution of the linear regression

$$\text{minimize} \ \sum_{\ell=1}^{16} \sum_{t=2012}^{2019} w_{t,\ell} \left(\hat{d}^{\mathrm{st}_\ell}_t - \beta^{\mathrm{st}_\ell} \Delta^{\mathrm{st}_\ell}_t \right)^2 \tag{5}$$

where $\hat{d}^{\mathrm{st}_\ell}_t$ are the observed total number of deaths in state st_ℓ in years t. We have chosen 2012 as the starting year because end of 2011 the German Federal Statistical Office evaluated and changed the method of calculating the mortality probabilities and the population tables. The weights $w_{t,\ell}$ should equal the reciprocal of the variance of the number of deaths $\hat{d}^{\mathrm{st}_\ell}_t$. The number of deaths is according to (4) a sum of binomially distributed independent random variables $D \sim \mathrm{bin}(n,p)$ with parameters $n = \frac{1}{2} l^{\mathrm{st}_\ell}_{x,t}$ and $p = \frac{1}{2}(q^{\mathrm{st}_\ell}_{x,t} + q^{\mathrm{st}_\ell}_{x+1,t})$. Because the mortality probabilities are close to zero, $\mathbb{V}D = np(1-p) \approx np = \mathbb{E}D$, hence we put

$$w_{t,\ell} = \frac{1}{\hat{d}^{\mathrm{st}_\ell}_t} \approx \frac{1}{\mathbb{V}D^{\mathrm{st}_\ell}_t}. \tag{6}$$

Taking partial derivatives in (5) leads to the linear equations

$$-2 \sum_{t=2012}^{2019} \frac{1}{\hat{d}^{\mathrm{st}_\ell}_t} (\hat{d}^{\mathrm{st}_\ell}_t - \beta^{\mathrm{st}_\ell} \Delta^{\mathrm{st}_\ell}_t) \Delta^{\mathrm{st}_\ell}_t = 0 \tag{7}$$

yielding β^{st_ℓ} for $\ell = 1, \ldots, 16$.

Finally we slightly modify this approach: the method does not take care of the already calculated expected total number of deaths $\mathbb{E}D_t$ for the whole of Germany in the pandemic years stated in Table 2. Clearly, $\sum_\ell \triangle^{\mathrm{st}_\ell}_t = \mathbb{E}D_t$, i.e. the sum of the not adjusted expected deaths in all states equals the expected number of deaths in Germany, and distributing the expected number of deaths 2020–2023 according to the method proposed in [20, Table 1 and 2] onto the pandemic years P_t, $t = 1,2,3$, one has $\sum_\ell \triangle^{\mathrm{st}_\ell}_{P_i} = \mathbb{E}D_{P_i}$. But the obtained minimizers are not additive in the sense that also $\sum_\ell \beta^{\mathrm{st}_\ell} \triangle^{\mathrm{st}_\ell}_{P_i}$ would still equal $\mathbb{E}D_{P_i}$. To take care of this, we fix $i \in \{1,2,3\}$, and optimize 5 under the constraint in β^{st_ℓ} that

$$\sum_{\ell=1}^{16} \mathbb{E}D^{\mathrm{st}_\ell}_{P_i} = \sum_{\ell=1}^{16} \beta^{\mathrm{st}_\ell} \triangle^{\mathrm{st}_\ell}_{P_i} = \mathbb{E}D_{P_i}.$$

From a mathematical point of view we introduce a Lagrange multiplier and minimize

$$\sum_{\ell=1}^{16} \sum_{t=2012}^{2019} \frac{1}{\hat{d}^{\mathrm{st}_\ell}_t} \left(\hat{d}^{\mathrm{st}_\ell}_t - \beta^{\mathrm{st}_\ell} \Delta^{\mathrm{st}_\ell}_t \right)^2 - \lambda \left(\sum_{\ell=1}^{16} \beta^{\mathrm{st}_\ell} \Delta^{\mathrm{st}_\ell}_{P_i} - \mathbb{E}D_{P_i} \right).$$

This results in the state factors $\beta^{\mathrm{st}_\ell}_{P_i}$ given in Table 3, which depend in principle on the pandemic year, but in fact turn out to be nearly independent of P_i: the maximal difference between $\beta^{\mathrm{st}_\ell}_{P_i}$ for $i = 1,2,3$ is 0.00018. Hence from now on for the ease of notation we write β^{st_ℓ} instead of $\beta^{\mathrm{st}_\ell}_{P_i}$.

Table 3: State factors β^{st_ℓ} for the German states

state	β^{st_ℓ}
Baden-Württemberg	0.922
Bavaria	0.961
Berlin	0.986
Brandenburg	1.036
Bremen	1.024
Hamburg	0.968
Hesse	0.970
Mecklenburg-Vorpommern	1.074
Lower Saxony	1.025
North Rhine-Westphalia	1.030
Rhineland-Palatinate	1.008
Saarland	1.081
Saxony	0.995
Saxony-Anhalt	1.112
Schleswig-Holstein	1.021
Thuringia	1.062

We demonstrate the effect of this state factors for the two extreme cases Baden-Württemberg and Saxony-Anhalt. Figure 2 shows for the prepandemic years 2012-2019 the unadjusted estimated excess deaths $\hat{d}_t^{\mathrm{st}_\ell} - \triangle_t^{\mathrm{st}_\ell}$ based on the German-wide mortality probabilities of the life table 2017/19, and the estimated excess deaths $\hat{d}_t^{\mathrm{st}_\ell} - \mathbb{E}D_t^{\mathrm{st}_\ell}$ when the estimates are adjusted for the federal-state specific deviations in mortality probability using the state factors.

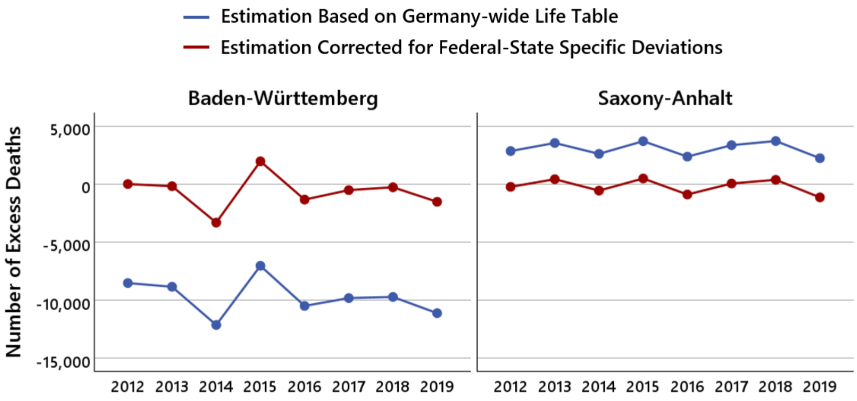

Figure 2: Illustration of the problem of using Germany-wide mortality probabilities of the life table 2017/19 for the estimations of the state-specific excess mortalities using the data form the federal states of Baden-Württemberg and Saxony-Anhalt that deviate most strongly from the Germany-wide mortality probabilities. The blue dots show the number of estimated excess deaths based on the German-wide mortality probabilities of the life table 2017/19, the red dots show the number of estimated excess deaths when the estimates are adjusted for the state-specific deviations in mortality probability using the state factors.

The state factors derived in this way finally allow us to compute the expected number of deaths $\mathbb{E}D_{P_i}^{\mathrm{st}_\ell}$ for each state, and by comparison to the observed number of deaths, the absolute excess mortality $d_{P_i}^{\mathrm{st}_\ell} - \mathbb{E}D_{P_i}^{\mathrm{st}_\ell}$ and the relative excess mortality $(d_{P_i}^{\mathrm{st}_\ell} - \mathbb{E}D_{P_i}^{\mathrm{st}_\ell})/\mathbb{E}D_{P_i}^{\mathrm{st}_\ell}$ in each federal state for the first (04/2020–03/2021), second (04/2021–03/2022), and third (04(2022–03/2023) pandemic year.

It is illuminating to calculate the correlations between the state factors and the other state-specific quantities examined in this study (for a description, see below). The state factors are strongly correlated with mean age ($r = 0.76$, $p < 0.001$), proportions of people in peed of care ($r = 0.80$, $p < 0.001$), and the Gross Domestic Product (GDP) which represents a measure of the wealth of a federal state ($r = -0.67$, $p = 0.005$). That is, compared to the German-wide mortality probability reported in the Life Tables, federal states with a higher average age, a higher proportion of people in need of care, and lower wealth as measured by the GDP show higher mortality probabilities. The three quantities that correlated with the state factors were also highly correlated with each other as well (mean age/proportion of people in need of care: $r = 0.85$, $p < 0.001$; mean age/GDP: $r = -0.88$, $p < 0.001$; proportion of people in need of care/GDP: $r = -0.76$, $p < 0.001$). The state factors were uncorrelated with all COVID-19 related quantities (excess mortality: all $p > 0.159$; COVID-19 deaths: all $p > 0.481$; COVID-19 infections: all $p > 0.458$; COVID-19 measures: all $p > 0.566$; COVID-19 vaccination rates: all $p > 0.877$).

2.3 Correlational Analysis

In order to investigate which state-specific quantities covary with the excess mortality observed in a federal state, several key quantities were collected, which are described below. All of the data used in the present study can be downloaded from https://osf.io/xg8eu/.

2.3.1 Number of COVID-19 deaths

The monthly number of COVID-19 deaths for each German federal state is reported by the Robert Koch Institute. For data security reasons, numbers below four are only states as "< 4". In such cases, the value was set to two. For a few federal states no values were reported during a few summer month in 2020. In such cases, the value was set to zero based on the assumption that no COVID-19 deaths occurred in these months. To achieve comparability of the values despite the different population sizes of the different federal states, the number of COVID-19 deaths reported for a federal state was standardized based on the expected number of deaths estimated for a federal state. That is, we determined for each federal state the percentage of the number of reported COVID-19 deaths relative to the number of expected all-cause deaths. These values reflect the extent to which COVID deaths have occurred in a federal state in relation to the usually expected number of deaths from all other causes of death.

2.3.2 Number of COVID-19 infections

The cumulative number of COVID-19 infections for each Germany federal state was daily reported by the Robert Koch Institute. To examine the relationship with excess mortality, the cumulative number of COVID-19 infections reported at the end of each of the three pandemic years were retrieved. To achieve comparability of the values despite the different population sizes of the different federal states, the cumulative number of reported COVID-19 infections was divided by the yearly total population of a federal state.

2.3.3 Strength of Measures Taken Against COVID-19

In Germany, the containment measures were determined at the level of the individual federal states, so that the intensity of the measures taken varies between individual federal states. Which measures have been imposed over time was recorded on a daily basis by the Federal Ministry for Economic Affairs and Climate on a so-called Corona data platform [17]. The measures imposed in a federal state are summarized in a Corona Severity Index (CSI) that provides information about the dynamics and severity of the imposed measures. The calculation of the CSI is methodically based on the Oxford Stringency Index, that is, the imposed measures are evaluated according to several categories and summed up based on a point system that ranges from zero (no measures at all) to 100 (maximal strength). To determine the strength of imposed measures in a federal state in a pandemic year, the mean across the monthly Corona Severity Index was calculated.

2.3.4 Vaccination Rates

The percentage of people vaccinated (first vaccinations, second vaccinations, third vaccinations) in each of the German federal states was daily reported by the Robert Koch Institute. To examine the relationship with excess mortality, the vaccination rates reported at the end of each month during the three pandemic years were retrieved. In the third pandemic year, the variation in vaccination rates across the federal states over the months of the pandemic year was extremely stable (rate of second vaccinations: all $r > 0.99$; rate of third vaccinations, all $r \geq 0.96$), and the variation in vaccination rates for second and third vaccinations was highly similar as well (April 2022: $r = 0.82$; since June 2022: all $rs > 0.88$). In the second pandemic year, the variation in vaccination rates across the federal states over the months of the pandemic year reached extremely stable values as well (rate of second vaccinations: since August 2021: all $r > 0.99$; rate of third vaccinations: since January 2022: all $r > 0.98$, and the variation in vaccination rates for second and third vaccinations reached highly similar levels as well (April 2022: $r = 0.82$; since June 2022: all $r > 0.88$). Due to this highly similar pattern in vaccination rates across time and types of vaccination, we decided to use the percentage of triple vaccinated people at the end of a pandemic year as an indicator for the vaccination rate in a federal state, and to report the correlations between excess mortality and the monthly rates of double and triple vaccinated people in the appendix.

2.3.5 Gross Domestic Product

The Gross Domestic Product represents a measure of the wealth of a federal state which is in Germany provided in a joint statistics portal of the statistical offices of the federal states [28]. To control for differences in population sizes, the GDP per capita was used which shows a federal state's GDP divided by its total population. The variations in the GDPs per capita across the federal states in the years 2020, 2021, and 2022 were extremely similar (all $r > 0.99$). Due to this extremely similar pattern across time, we decided to use the mean GDP per capita across the years 2020 to 2022.

2.3.6 Poverty Rate

To measure poverty in Germany, the German Federal Statistical Office determines the rate of people that are below the poverty risk threshold (i.e., the at-risk-of-poverty rate) for each of the federal states [29]. According to this measurement, people who have less than 60% of the median income of the population are considered to be at risk of poverty. The variations in the at-risk-of-poverty rates across the federal states in the years 2020, 2021, and 2022 were extremely similar (all $r > 0.96$). Due to this extremely similar pattern across time, we decided to use the mean at-risk-of-poverty rate across the years 2020 to 2022.

2.3.7 Mean Age

The mean age of the population of a federal state for the three pandemic years was calculated based on the age-dependent population size data provided by the German Federal Statistical Office for each year. The variations in mean age across the federal states in the years 2020, 2021, and 2022 were extremely similar (all $r > 0.99$). Due to this extremely similar pattern across time, we decided to use the mean age across the years 2020 to 2022.

2.3.8 Proportions of People in Need of Care

The proportions of people in need of care in a federal state is provided by the German Federal Statistical Office [11]. The most current data corresponds to the status as of December 31, 2021, and we have used this data.

3 Results

3.1 Excess Mortality in German States

Using the state factors derived in Section 2.2.1, we compute the expected number of deaths for each of the German states st_ℓ, $\ell = 1, \ldots, 16$, for the three pandemic years P_i, $i = 1, 2, 3$ and compare them in Table 4 to the observed values $\hat{d}^{\mathrm{st}_\ell}_{P_i}$.

Table 4: Expected and observed number of deaths in 16 German states

	04/20–03/21		04/21–03/22		04/22–03/23	
state	exp.	obs.	exp.	obs.	exp.	obs.
Baden-Württemberg	115,231	116,463	116,699	119,701	118,010	126,401
Bavaria	140,645	145,234	142,187	147,897	143,453	153,615
Berlin	37,078	38,671	37,302	37,541	37,676	39,660
Brandenburg	34,500	36,223	35,120	36,555	35,597	37,739
Bremen	8,061	8,082	8,112	8,290	8,106	8,999
Hamburg	18,337	18,607	18,482	18,881	18,583	20,016
Hesse	69,356	72,041	70,061	71,297	70,626	76,237
Mecklenburg-Vorpommern	22,787	22,519	23,272	24,418	23,556	25,206
Lower Saxony	98,431	97,408	99,760	100,318	100,797	110,388
North Rhine-Westphalia	215,195	216,122	217,136	221,380	218,411	237,229
Rhineland-Palatinate	49,619	49,568	50,157	50,967	50,543	54,225
Saarland	13,835	13,890	13,949	14,414	13,999	15,519
Saxony	57,330	65,674	57,365	60,999	57,528	60,981
Saxony-Anhalt	34,029	35,745	34,291	36,136	34,352	37,235
Schleswig-Holstein	36,647	35,610	37,405	37,025	37,998	41,298
Thuringia	30,576	32,204	30,829	33,281	30,865	33,136
total	981,656	1,004,061	992,127	1,019,100	1,000,102	1,077,884

The sum of all states in the last row clearly equals the numbers for Germany stated already in Table 2. Note that the observed number of deaths in 2023 and thus also in the last three months of P_3 is still preliminary.

The excess mortality is the difference between the observed values and the expected values

$$\hat{d}^{\mathrm{st}_\ell}_{P_i} - \mathbb{E}D^{\mathrm{st}_\ell}_{P_i}.$$

We also state in Table 5 the relative excess mortality

$$\frac{\hat{d}^{\mathrm{st}_\ell}_{P_i} - \mathbb{E}D^{\mathrm{st}_\ell}_{P_i}}{\mathbb{E}D^{\mathrm{st}_\ell}_{P_i}}.$$

Table 5: Relative excess mortality in 16 German states

state	04/20–03/21	04/21–03/22	04/22–03/23
Baden-Württemberg	1.07%	2.57%	7.11%
Bavaria	3.26%	4.02%	7.08%
Berlin	4.29%	0.64%	5.27%
Brandenburg	4.99%	4.09%	6.02%
Bremen	0.26%	2.19%	11.02%
Hamburg	1.48%	2.16%	7.71%
Hesse	3.87%	1.76%	7.94%
Mecklenburg-Vorpommern	-1.17%	4.92%	7.00%
Lower Saxony	-1.04%	0.56%	9.51%
North Rhine-Westphalia	0.43%	1.95%	8.62%
Rhineland-Palatinate	-0.10%	1.62%	7.28%
Saarland	0.40%	3.34%	10.86%
Saxony	14.56%	6.34%	6.00%
Saxony-Anhalt	5.04%	5.38%	8.39%
Schleswig-Holstein	-2.83%	-1.02%	8.68%
Thuringia	5.32%	7.95%	7.36%

3.2 Correlation Matrix

Table 6 shows the correlations between excess mortality and the reported number of COVID-19 deaths and COVID-19 infections, the strength of the measures, the vaccination rates, the GDP, the poverty rate, the mean age, and the proportion of people in need of care.

Table 6: Correlation matrix

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1. Excess Mortality: Year 1																	
2. Excess Mortality: Year 2	.63**																
3. Excess Mortality: Year 3	-.52*	-.25															
4. COVID-19 Deaths: Year 1	.96**	.63**	-.56*														
5. COVID-19 Deaths: Year 2	.78**	.89**	-.37	.84**													
6. COVID-19 Deaths: Year 3	-.18	-.09	.32	-.06	.02												
7. COVID-19 Infections: Year 1	.90**	.58*	-.41	.94**	.77**	-.03											
8. COVID-19 Infections: Year 2	.70**	.82**	-.43	.69**	.78**	-.12	.67**										
9. COVID-19 Infections: Year 3	-.72**	-.63**	.71**	-.74**	-.70**	.36	-.72**	-.64**									
10. Strength of Measures: Year 1	.17	.05	.10	.27	.15	.09	.24	.20	.06								
11. Strength of Measures: Year 2	.10	.25	-.16	.03	.07	-.17	-.06	.19	-.32	-.16							
12. Strength of Measures: Year 3	-.09	-.07	-.11	-.06	-.16	.15	-.17	-.10	.01	-.14	.32						
13. Vaccination Rate: Year 2	-.80**	-.78**	.67**	-.81**	-.80**	.16	-.70**	-.80**	.74**	-.17	-.24	.04					
14. Vaccination Rate: Year 3	-.82**	-.81**	.65**	-.81**	-.85**	.30	-.68**	-.79**	.74**	-.13	-.15	.10	.96**				
15. Gross Domestic Product	-.19	-.39	.11	-.09	-.24	.56*	.01	-.17	.16	.00	.12	.09	.23	.41			
16. Poverty Rate	-.11	-.04	.52*	-.26	-.19	-.03	-.08	-.32	.08	-.40	.21	-.17	.26	.28	.11		
17. Mean Age	.28	.65**	-.03	.19	.46	-.36	.04	.37	-.21	.06	.15	.08	-.37	-.52*	-.88**	-.10	
18. People in Need of Care	.32	.63**	.12	.21	.44	-.17	.16	.26	-.18	-.12	.07	.06	-.36	-.43	-.76**	.26	.85**

Note. ** p < .01; * p < .05; N = 16

In this section, we only point out the observed main correlative patterns, which will be discussed in detail in the following discussion section. Two correlation patterns stand out very clearly. The first correlative pattern concerns the association between excess mortality and COVID-19-related factors. In the first and second pandemic year, the excess mortality observed in an federal state is highly correlated with the reported number of COVID-19 deaths (first pandemic year: $r = 0.96$, $p < 0.001$; second pandemic year: $r = 0.89$, $p < 0.001$) and the reported number of COVID-19 infections (first pandemic year: $r = 0.90$, $p < 0.001$; second pandemic year: $r = 0.82$, $p < 0.001$). This pattern changes in the third pandemic year where the correlation between excess mortality and the reported number COVID-19 deaths is no longer significant ($r = 0.32$, $p = 0.23$), while the correlation between excess mortality and the reported number COVID-19 infections remains significant ($r = 0.71$, $p = 0.002$).

The second correlation pattern that stands out concerns the association between vaccination rates and excess mortality as well as the number of COVID-19 deaths and COVID-19 infections. The vaccination rate in a federal state in the second pandemic year is highly negatively correlated with the excess mortality and the reported number of COVID-19 deaths and COVID-19 infections, both in the first pandemic year (excess mortality: $r = -0.80, p < 0.001$; COVID-19 deaths: $r = -0.81, p < 0.001$; COVID-19 infections: $r = -0.70$, $p = 0.002$) and the second pandemic year (excess mortality: $r = -0.78, p < 0.001$; COVID-19 deaths: $r = -0.80, p < 0.001$; COVID-19 infections: $r = -0.80, p < 0.001$). In the third pandemic year, this pattern changes fundamentally. The vaccination rate in a federal state in the third pandemic year is now positively correlated with the excess mortality and the reported number of COVID-19 deaths and COVID-19 infections (excess mortality: $r = 0.65, p = 0.006$; COVID-19 deaths: $r = 0.30, p = 0.254$; COVID-19 infections: $r = 0.74$, $p = 0.001$).

With regard to all other correlations, no pattern can be recognized; only a few smaller and time-limited correlations can be observed. Excess mortality in the second pandemic year correlates moderately with mean age ($r = 0.65$, $p = 0.006$) and the proportion of people in need of care ($r = 0.63$, $p = 0.009$), two variables that are highly correlated by themselves ($r = 0.85$, $p = 0.001$). In the third pandemic year, excess mortality correlates moderately with the poverty rate ($r = 0.52$, $p = 0.041$), and the reported number of COVID-19 deaths correlates moderately with the GDP ($r = 0.56$, $p = 0.024$). Due to the high number of correlations examined and the moderate size and unsystematic occurrence of these correlations, it can be assumed that these are probably correlations that become significant by chance and do not reflect true effects.

4 Discussion

The aim of the present study was to estimate excess mortality in the individual German federal states using scientifically sound methods, and to explore the relationship between excess mortality and several key state-specific quantities. The estimations of excess mortality based on the state-of-the-art method of actuarial science (Kuhbandner and Reitzner [9]) revealed that excess mortality substantially varied across the federal states in Germany, ranging from -2.83% to 14.56% in the first pandemic year (04/20 – 03/21), -1.02% to 7.95% in the second pandemic year (04/21 – 03/22), and 5.27% to 11.02% in the third pandemic year (04/22 – 03/23).

4.1 COVID-19 related correlations

Regarding possible explanations of the variation of excess mortality across federal states, the correlation analysis showed that in the first two pandemic years excess mortality observed in a federal state was strongly correlated with the reported numbers of COVID-19 deaths and infections: the higher the relative number of reported COVID-19 deaths and infections, the higher the relative excess mortality (for an illustration, see Figure 3A). Such a correlational pattern clearly suggests that the variation of excess mortality across federal states may stem from the fact that different federal states were affected to different extent by COVID-19.

As can clearly be seen in Figure 3A, the reported number of COVID-19 deaths largely exceeds the observed amount of excess mortality in both the first and the second pandemic year. If the reported number of COVID deaths matched the observed excess mortality, the data points for the federal states should move along the dashed line. However, in the first and second pandemic year, the data points are instead consistently well above the dashed line, which means that, relative to the number of expected deaths, the reported number of COVID deaths was substantially higher than the number of excess deaths.

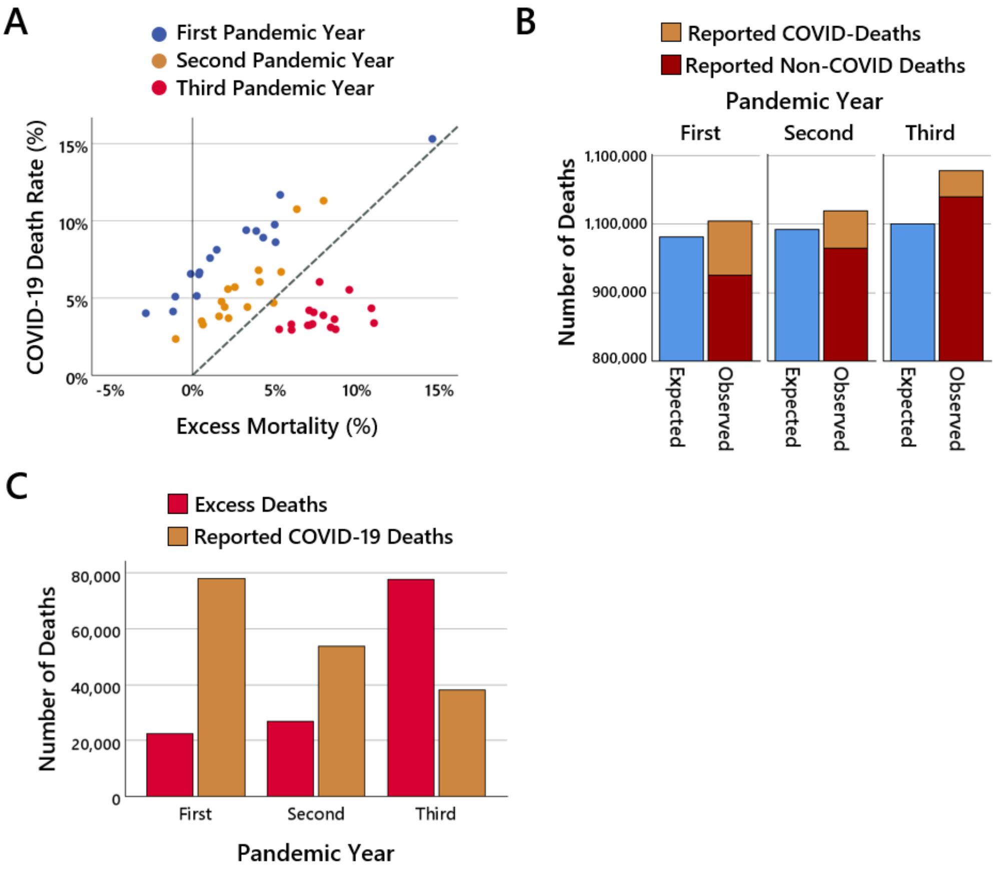

Figure 3: **COVID-19 related correlation results.** (A) shows the relationship between the relative excess mortality and the relative number of COVID-19 deaths (in relation to the number of expected deaths) for each federal state in the first (blue dots), second (orange dots), and third (red dots) pandemic years. The dashed line indicates what would be the case if the reported number of COVID-19 deaths exactly matched the number of observed excess deaths. (B) shows the total number of expected deaths (blue bars), the total number of reported COVID-19 deaths (orange bars), and the total number of reported Non-COVID deaths (red bars), and (C) shows the total number of excess deaths (red bars) and the total number of reported COVID-19 deaths (orange bars) across all federal states in the three pandemic years.

This observation is illustrated in Figure 3B in more detail where the total numbers of expected deaths, reported COVID-19 deaths, and reported Non-COVID deaths across all federal states is shown. In the first pandemic year, 981,656 deaths were expected but 1,004,061 deaths observed, meaning there were 22,405 more deaths observed than expected. However, at the same time, 78,185 COVID-19 deaths were reported. That is, the number of reported COVID-19 deaths was 3.5 times higher than the number of observed excess deaths, and the number of reported Non-COVID-deaths was 0.94 times lower than the number of expected deaths. In the second pandemic year, 992,127 deaths were expected but 1,019,100 deaths observed, meaning there were 26,973 more deaths observed than expected. However, at the same time, 53,883 COVID-19 deaths were reported. That is, the number of reported COVID-19 deaths was 2.0 times higher than the number of observed excess deaths, and the number of reported Non-COVID-deaths was 0.97 times lower than the number of expected deaths.

This surprising pattern may have occurred due to two possible reasons. First, it could be that the measures taken against COVID-19 have reduced the number of Non-COVID deaths, and that the reported COVID-19 deaths are all true excess deaths. However, this possibility is highly unlikely given the observed correlations between the decline in Non-COVID deaths observed in a federal state and the strength of the measures taken. In the first pandemic year, a zero correlation is observed ($r = 0.06$, $p = 0.823$), and in the second pandemic year, even a tendentially negative correlation is observed ($r = -0.38$, $p = 0.152$), that is, the stronger the measures taken, the smaller the decline in the number of observed Non-COVID deaths.

It is therefore more likely that the second possibility is the case: Obviously, COVID-19 has replaced other commonly occurring causes of death. One possible mechanism may be that the spread of to the SARS-CoV-2 virus has inhibited the viral reproduction of other common viruses, a phenomenon called viral interference, which has been assumed to occur for the SARS-CoV-2 virus (Deleveaux et al. [7]). Consistent with such a hypothesis, a global decline in influenza was observed during the first two pandemic years (Bonacina [3]), which resulted in the elimination of an usually occurring cause of death. Another possible mechanism may be an inflationary use of the diagnosis “COVID-19 death”. Since the diagnosis “COVID-19 death” is mainly based on the presence of a current positive SARS-CoV-2 PCR test, such a diagnosis does not clearly specify whether a death reported as “COVID-19 deaths” was indeed caused by a SARS-CoV-2 infection or whether the deceased person died from some other cause of death with a coincidentally occurring SARS-CoV-2 infection. Accordingly, it may be that a larger proportion of deaths reported as ”COVID-19 death” actually died from other causes of death, a hypothesis which is indeed supported by autopsy studies (e.g., von Stillfried [33]).

Regardless of which of the two possibilities is primarily responsible for the observed pattern, in both cases this would mean that the reported number of COVID-19 deaths significantly overestimates the burden of COVID-19 on mortality, and that the true excess mortality caused by COVID-19 would be on the same scale as previous strong flu waves, such as the flu season 2017/2018 where it is estimated that 25,100 people in Germany died due to influenza (Robert Koch-Institute [25]). Taken together, the picture that is suggested by the COVID-19-related findings for the first and second pandemic years is that the excess mortality observed was very likely driven by COVID-19. However, the observed excess mortality is in both years in the range of the excess mortality usually observed during strong flu waves, which would mean that COVID-19 was not an extraordinary pandemic, at least in Germany.

This picture changes fundamentally in the third year of the pandemic. As can be seen in Figure 3A, suddenly the correlation between excess mortality and the reported number of COVID-19 deaths largely disappears, and suddenly the number of excess deaths largely exceeds the reported number of COVID-19 deaths. As can be seen in Figure 3B, in the third pandemic year, 1,000,102 deaths were expected but 1,077,884 deaths observed, meaning there were 77,782 more deaths observed than expected. However, at the same time, only 38,062 COVID-19 deaths were reported. That is, the number of reported COVID-19 deaths was only less than half the number of excess deaths, and the number of reported Non-COVID-deaths was 1.04 times higher than the number of expected deaths.

The same pattern was observed in every single federal state. In all but one of the federal states (Saxony), excess mortality increased from the first to the third year of the pandemic, while in all but one (Lower Saxony) COVID-19 deaths decreased. However, the same pattern emerged in both exceptional federal states. In Saxony, COVID-19 deaths decreased more than excess mortality, and in Lower Saxony, excess mortality increased more than COVID deaths.

Taken together, the picture that is suggested by the COVID-19-related findings for the third pandemic year is that there was an exceptionally high excess mortality far above the usual level during strong flu waves, which can hardly be explained by COVID-19 but must be due to other factors.

Finally, a closer look at the pattern observed in the first and second pandemic years suggests that it is already becoming apparent in the second pandemic year that an additional factor is beginning to contribute to excess mortality. A striking observation is that excess mortality and the reported number of COVID-19 deaths develop in opposite directions from the first to the second year of the pandemic. Although the number of reported COVID deaths decreases by 24,302, the number of excess deaths increases by 4,568. This contrasting developmental pattern makes it unlikely that the excess mortality observed in the second pandemic year can be fully explained by COVID-19. Rather, this finding suggests that a second non-COVID-related factor appears to increasingly determine excess mortality.

4.2 Vaccination-related Correlations

The second striking correlation pattern are the high correlations between vaccination rate, excess mortality and the reported number of COVID-19 deaths and infections of a federal state (for an illustration, see Figure 4).

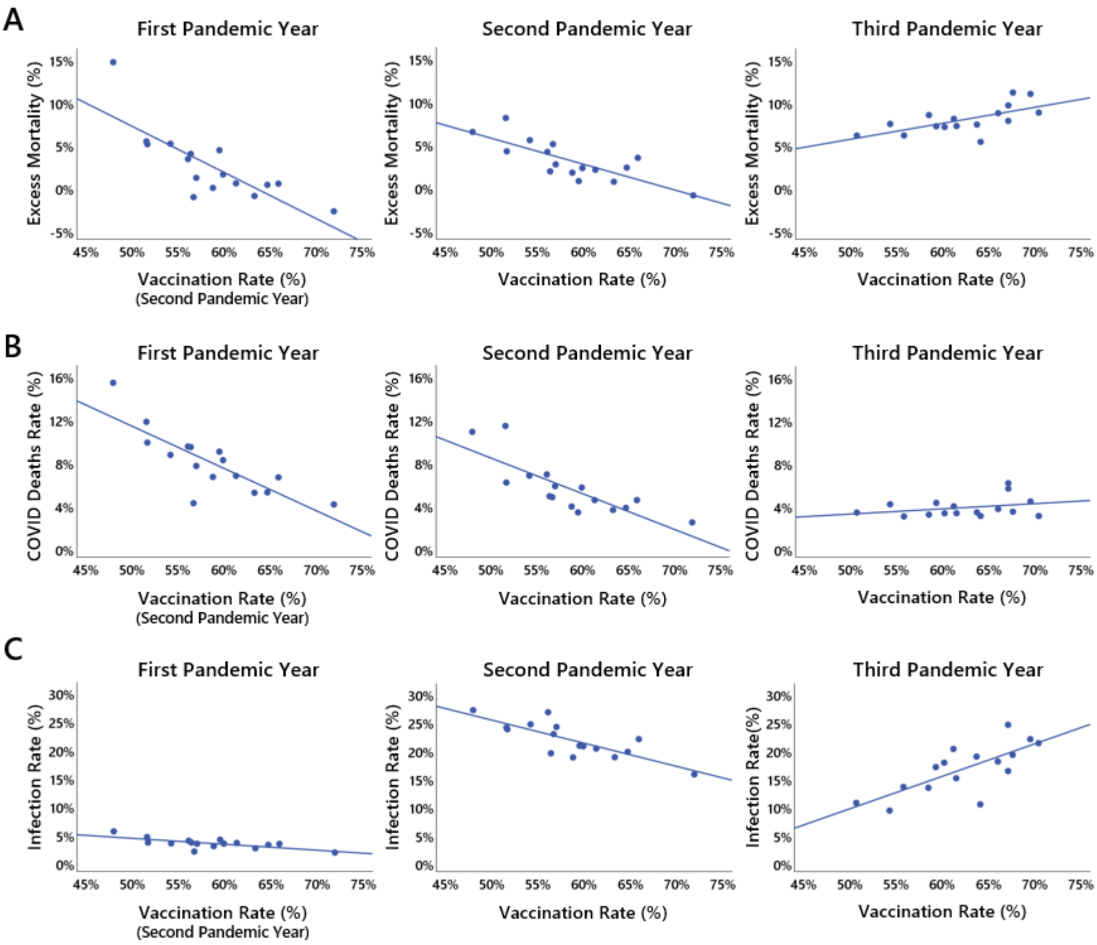

Figure 4: **Vaccination-related correlations.** The relationship between vaccination rate in a federal state and (A) excess mortality, (B) the reported number of COVID-19 deaths relative to the number of expected deaths, and (C) the reported number of SARS-CoV-2 infections relative to the population size is shown in the first, second, and third pandemic year.

In a previous study (Thum [32]), it was reported that the excess mortality observed in a federal state in the second half of 2021 was negatively correlated with the COVID-19 vaccination rate in a federal state. The present findings replicate and extend this finding by showing that in the second pandemic year in which large parts of the population were double and triple vaccinated, both excess mortality and the number of reported COVID-19 deaths and infections were negatively correlated with the vaccination rate of a federal state.

At first glance, one is tempted to interpret this finding as evidence of the effectiveness of the vaccinations, as various media did with regard to the findings of the previous study by Thum. However, the fact that the vaccination rate in the second pandemic year is also correlated to exactly the same extent with the excess mortality and the reported number of COVID-19 deaths and infections in the first pandemic year where hardly anyone was vaccinated – the rate of fully vaccinated persons in Germany was 0.5% at the end of January 2021, 2.5% at the end of February 2021 and 4.9% at the end of March 2021 – speak against such an interpretation. Rather, this indicates that the negative correlation between vaccination rate and excess mortality and the reported number of COVID-19 deaths and infections observed in the second pandemic year is due to the effect of a third variable.

The negative correlation between the vaccinations administered in the second pandemic year and the reported numbers of COVID-19 deaths and infections in the first pandemic year indicate an interesting fact: Apparently, the less a federal state was affected by COVID-19 in the first pandemic year, the more people were vaccinated in the second pandemic year. At the same time, there is a strong correlation between the reported numbers of COVID-19 deaths and infections in the first and second pandemic year, indicating that the extent of being affected by COVID-19 was highly stable across federal states from the first to the second pandemic year. Taken together, this pattern clearly suggests that the negative correlation between vaccination rate and excess mortality and the reported numbers of COVID-19 deaths and infections does not reflect a causal effect of the vaccinations. Instead, this correlation seems to stem from the fact that vaccination rates were highest in the federal states that were least affected by COVID-19.

The fact that the size of the negative correlation between vaccination rate and excess mortality and the reported number of COVID-19 deaths did not increase in size from the first to the second pandemic year rather suggests that the vaccinations had no beneficial effect. If the vaccinations were effective, the federal states with the highest vaccination rates would have benefited the most, which means that the correlations between vaccinations and mortality observed in the first year of the pandemic should have been even more negative in the second year of the pandemic, which is not the case.

This is further supported by an analysis of the increase in excess mortality from the first to the second year of the pandemic. Figure 5 shows the increase in excess mortality from the first to the second and third pandemic years in percentage points.

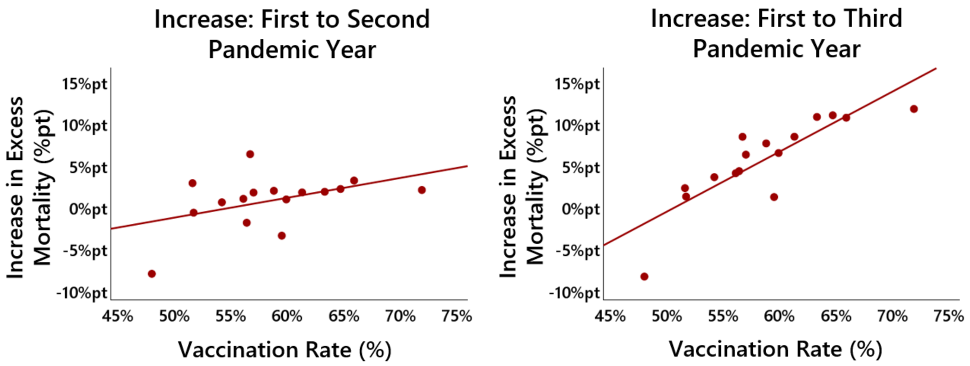

Figure 5: **Increase in Excess Mortality and Vaccinations.** The increase in excess mortality from the first to the second and third pandemic years in percentage points in the individual federal states is shown as a function of the vaccination rate in a federal state.

The most obvious expectation of an effective vaccination would be that the increase in excess mortality would be lowest in the federal states in which the most vaccinations were administered. However, the opposite is the case. Already in the second pandemic year, a moderately strong positive correlation is observed ($r = 0.45$, $p = 0.081$), and in the third pandemic year, a strong correlation is observed ($r = 0.85$, $p < 0.001$), indicating that the increase in excess mortality is the higher the higher the vaccination rate. Importantly, as can be seen in Figure 5, a continuous increase in excess mortality with increased vaccination rates can be observed even in the middle range of the observed vaccination rates, which rules out that the observed correlations could be driven by the extreme values.

The impression that the negative relationship between the vaccinations and excess mortality increases from the second to the third pandemic year is further supported when we look at the correlations between vaccination rate and excess mortality and COVID-19 deaths and infections in the third year of the pandemic. As can be seen in the Figure 4 above, the correlation pattern fundamentally changes from the second to the third pandemic year. Now, positive correlations are observed between vaccination rate and excess mortality and the reported number of COVID-19 deaths and infections: The higher the vaccination rate, the higher the observed excess mortality and the reported number of COVID-19 deaths and infections. This is exactly the opposite of what one would expect from an effective vaccination: as the vaccination rate increases, the number of infections increase as well as the number of infection-related deaths and the overall number of deaths.

The observation that excess mortality and the reported number of COVID-19 deaths and infections in the third year of the pandemic are the higher the more people have been vaccinated in a federal state is an irrefutable empirical fact. Such a pattern would be expected if the vaccinations had caused negative effects instead of positive effects. However, since this is a correlative relationship, this observation does not necessarily mean that the observed differences in mortality between federal states can be causally attributed to the different vaccination rates. Due to this fact, it is important to explore various possibilities how such a correlative pattern as observed in the third year of the pandemic could arise, even though the vaccinations did not have any negative effects or still positive effects. This will be done next.

The negative correlations observed in the second year of the pandemic can be attributed to the third variable that vaccinations were highest in the federal states that were least affected by COVID-19 in the first pandemic year. Thus, the question arises whether this can possibly also explain the positive correlations observed in the third year of the pandemic. Already the fact that the correlations between vaccinations and excess mortality and the reported number of COVID-19 deaths and infections change from the second to the third pandemic year from negative to positive makes this seem unlikely. If the fact that vaccinations were highest in the federal states that were least affected by COVID-19 in the first pandemic year were to represent a third variable explanation for the positive correlations observed in the third pandemic year, another factor beyond the vaccinations must have suddenly appeared.

Finding such a possible factor is difficult. One factor could perhaps be that the more people have already been affected by COVID-19, the smaller the number of people susceptible to COVID-19, which would mean that the initially more severely affected federal states are increasingly less affected. First, it is important to note that vaccinations are being administered with the aim of reducing the number of people susceptible to COVID-19. This means that an effective vaccination would actually reduce the number of susceptible people and thus cancel out the effect of such a third variable. If such a third variable were to explain the observed positive correlations between vaccinations and mortality, it would mean that the positive correlations are not due to a negative effect of the vaccinations, but at the same to time this would mean that the vaccinations did not produce positive effects.

However, the possibility that such a third variable might explain the positive correlation between vaccinations and excess mortality is anyway unlikely due to at least two reasons. First, if this third-variable explanation were true, then the transition from negative to positive correlations should be gradual. However, the observed pattern corresponds to a sudden change: correlations of exactly the same size are observed in the first and second pandemic year, and then the correlations suddenly jump in the exact opposite direction in the third pandemic year. Second, when statistically controlling for the possible third variable of the extent of being affected by excess mortality in the first two pandemic years (sum of excess mortality across the first and second pandemic year), the positive correlation between vaccination rate and excess mortality does not change (partial $r = 0.60$, $p = 0.018$).

Another theoretical possibility is that the vaccinations might have been effective and prevented deaths and infections despite the positive correlations between vaccination rate and excess mortality and the reported number of COVID-19 deaths and infections. That is, although mortality and the incidence of COVID-19 were highest in the federal states with the highest vaccination rates, without the vaccinations, the excess mortality and incidence of COVID-19 might still have been substantially higher in these federal states. This is unlikely, because if that were the case, an additional factor beyond the vaccinations must have suddenly emerged from the second to the third pandemic year that hit precisely those federal states that until then had only been slightly affected by COVID-19. Furthermore, this possibility is also unlikely given the fact that the observed mortality and infection rates in the most heavily vaccinated federal states were already so high that not much room is left for such an explanation. That is, if the vaccinations were to be effective despite the observed high mortality and infection rates, unrealistically high mortality and infection rates would have to be assumed.

The observed correlation pattern reflects a spatial effect: the highest excess mortality was observed in the most vaccinated regions. As shown in our recent study (Kuhbandner and Reitzner [20]), a similar relationship between vaccinations and excess mortality is observed on the temporal level. In the second pandemic year, during the months with a high number of vaccinations, also a high number of excess deaths was observed, a relationship which is especially pronounced for the third vaccinations. After the third vaccinations were completed, excess mortality began to rise continuously in the third year of the pandemic, reaching a maximum of 28% in December 2022. The fact that particularly high excess mortality occurs both in regions and in time windows in which many vaccinations took place strengthen the empirical evidence that the vaccinations may have had a negative effect instead of a positive effect.

To summarize, from a statistical perspective, the observed pattern is as follows: In the first year of the pandemic, there is a very strong correlation between excess mortality and the reported number of COVID-19 deaths, suggesting a causal connection between excess mortality and COVID-19. However, the reported number of COVID deaths greatly overestimates the excess mortality that has occurred, which is in line with strong flu waves in previous years. In the second year of the pandemic, a new excess mortality factor suddenly appears, which is reflected in the fact that the reported number of COVID-19 deaths decreases, but excess mortality increases. The fact that the increase in excess mortality in the second year of the pandemic is correlated both temporally and spatially with the number of vaccinations administered suggests that this new excess mortality factor could be the vaccinations. This hypothesis is further strengthened empirically by the fact that a highly positive correlation between vaccination rate and excess mortality is observed in the third pandemic year, suggesting a long-lasting negative effect of the vaccinations.

4.2.1 Possible Third-Variable Explanations

The results of the correlation analysis show a very clear and simple picture: There are only two variables that are systematically related to excess mortality: COVID-19 and the vaccination rate. The fact that the vaccination rate in the second year of the pandemic is already highly negatively correlated with excess mortality as well as with the reported number of COVID-19 deaths and infections in the first year of the pandemic clearly shows that the less a federal state was affected by COVID in the first pandemic year, the more vaccinations were administered. The fact that this negative correlation suddenly reverses in the third year of the pandemic clearly shows that a new factor must have suddenly emerged that drove up excess mortality and the number of COVID deaths and infections in the federal states that were initially least affected by COVID-19.

The fact that the vaccination rate is the only variable that is positively correlated with excess mortality as well as with the number of COVID-19 deaths and infections in the third pandemic year makes it seem very likely that this new factor was the COVID-19 vaccination. Further empirical evidence for such an interpretation is the analysis in which difference values with regard to the increase from the first to the second and third pandemic years are considered, whereby all time-stable state-specific third variables are controlled. The correlation between vaccinations and excess mortality remains intact when the state-specific burden of COVID-19 in the first two pandemic years is statistically controlled, this proves that the initial burden of COVID-19 is not a third variable that could explain the relationships between excess mortality and vaccinations. The fact that no systematic correlations are observed with regard to the other explored state-specific quantities excludes these as possible third variables as well.

Of course, although the correlation analysis provides a clear picture, it is still possible that there is still a hidden third variable responsible for the increase in excess mortality that is only randomly correlated with vaccinations. However, this third variable would have to meet a number of specifications: It would have to appear suddenly in the course of the second year of the pandemic and happen to have the greatest impact on precisely those federal states that have so far been least affected by COVID-19. In addition, this third variable would have to have had its strongest effect at precisely the times when vaccination was most widespread. Finding such a variable seems difficult.

4.2.2 Previous Vaccine Effectiveness Studies

While the fact that there are strong positive correlations between vaccinations and mortality that cannot easily be ruled out by third variables provide correlative evidence that the effect of the COVID-19 vaccinations on mortality is negative rather than positive, it is important to emphasize that such a conclusion is drawn from a statistical perspective and not from the perspective of the existing medical literature about the effectiveness of the COVID-19 vaccinations. In fact, from the perspective of the existing medical studies on vaccine effectiveness, the observed correlation pattern is highly surprising. For instance, according to a large meta-analysis covering the period up to the end of December 2022, across all SARS-CoV-2 strains, vaccine effectiveness directly after vaccination was 91% for mortality, with a slight decline to 86% in the long run (Wu et al. [34]).

However, the observed empirical correlations between vaccinations and excess mortality make it seem almost impossible that the vaccine effectiveness estimated in the medical studies could reflect the true effect of the vaccinations. Since in the federal states with the highest vaccination rates over 97 percent of the population over 60 years of age were at least fully vaccinated, it is almost impossible that the highest excess mortality is still observed in these federal states if the vaccine effectiveness was really that high. The only way there could occur a highly positive correlation between vaccinations and excess mortality despite a high effectiveness of the vaccinations would be if side effects outweigh the positive effects of the vaccinations. However, this is unlikely because the vaccination rate is not only positively correlated with excess mortality but also with the reported numbers of COVID-19 deaths and infections.

A possible explanation for the divergence between the reported correlation results and the results of previous vaccine effectiveness studies is that most studies on COVID-19 vaccine effectiveness are so-called observational studies where subjects are not randomly assigned to a vaccination group and an unvaccinated control group, but where the fate of people is followed who have decided for or against vaccination for whatever reasons. Due to the lack of randomization, observational studies provide less reliable results. If fewer cases of infections or deaths are found among vaccinated people than among unvaccinated people, this difference does not necessarily have to be due to the vaccination. It would be conceivable, for example, that people who have decided to be vaccinated would be more health-conscious overall and therefore perform better. The fact that such distorting effects exist in published observational studies has been shown, for example, by re-analyses of observational studies on the effect of flu vaccinations (Jefferson [18]). In particular, as reported in a recent study, this problem is compounded by the fact that contemporary observation studies published in medical journals typically fail to satisfy important quality criteria (Grosman and Scott [16]).

Interestingly, contrary to the results reported in the observation studies, in the large initial randomized controlled studies on the effectiveness of the COVID-19 vaccines, no positive effect of the vaccinations on mortality was observed. In the Pfizer-BioNTech vaccine effectivity study, for example, during the blinded two-month period, overall one more death was reported in the placebo group than in the vaccinated group (Thomas et al. [31]). According to the data reported in the 6-Month Interim Report of Adverse Event, in the group of vaccinated subjects 21 people died (two of which were unblinded subjects from the original control group that were vaccinated after the unblinding) whereas in the unvaccinated group only 17 people died (Michels et al. [23]). This pattern of findings suggests as well rather a negative than a positive effect of vaccinations on overall mortality, although it cannot be assessed whether the observed differences reflect a true or just a random effect because of the very small number of reported cases. However, a similar picture emerges when looking at serious adverse events which occurred more often. As shown in a re-analysis of the original trial data (Fraiman et al. [14]), statistically significant increases in serious adverse events were observed in the vaccination group. In particular, the excess risk of serious adverse events in the vaccination group was for times larger than the risk of COVID-19 hospitalization in the placebo group.

4.3 Strength of measures

It is noteworthy that not a single significant correlation is observed with regard to the strength of the measures taken in the three pandemic years, neither with excess mortality nor with the reported number of COVID-19 deaths or the number of SARS-CoV-2 infections. One would have expected at least some influence on the number of SARS-CoV-2 infections, and in the optimal case a reduction of the number of COVID-19 deaths and the excess mortality. The fact that not a single significant correlation was observed in any of the three pandemic years between the measures taken against COVID-19 and the number of COVID-19 deaths and infections makes it seem unlikely that the measures taken had any effect but only have produced statistical noise. Such a result is at first glance unexpected, given that the results of some extensive observational studies apparently show that at least some of the measures have had positive effects (e.g., Talic et al. [30]). However, in order to draw valid conclusions from observational studies, numerous possible sources of error must be excluded (e.g., confounding bias, population bias, spatial and/or temporal dependence bias, bias due to measurement errors). Critically, this is not done in many studies, as shown, for instance, in a recent systematic review on the effects of environmental and socioeconomic variables on the spread of COVID-19 (Barceló and Saez [2]). In all of the reviewed observational studies, to a greater or lesser extent, methodological limitations were detected that prevented the drawing of valid conclusions. Indeed, methodological problems have even been demonstrated to exist in studies published in the highest-ranking peer-reviewed journals (Kuhbandner et al. [19]). The empirical finding that there are no correlations between the strength of the measures taken in a federal state and the reported number of COVID-19 deaths and infections definitely shows that there is no simple direct effect, but that additional assumptions must be made in order to determine potential effects of the measures.

4.4 Stillbirths

In our previous study on excess mortality in Germany (Kuhbandner and Reitzner [20]), additionally the number of stillbirths was analyzed. The results showed a similar pattern than that observed for excess mortality: the number of stillbirths in Germany showed a relatively stable course during the previous years until the start of the vaccination campaign, after which a sudden increase was observed. To determine whether a similarity between excess mortality and stillbirths also exists at the level of the correlations with the vaccination rate of a federal state, we examined whether the number of stillbirths also varies as a function of the vaccination rate of a federal state.

The Federal Statistical Office has now published the final data for 2022 at the federal state level ([12], [13]). Note that the following analyses at the stillbirth level do not refer to pandemic years as before, but to calendar years, because the stillbirth data at the federal state level is only published at the annual level. As shown in Figure 6A, indeed also at the level of the correlations with the vaccination rate of a federal state (rate of second vaccinations at the end of the year in the age group 18-59; no more precise age breakdown available), the same pattern is observed at the level of stillbirths as at the level of excess mortality.

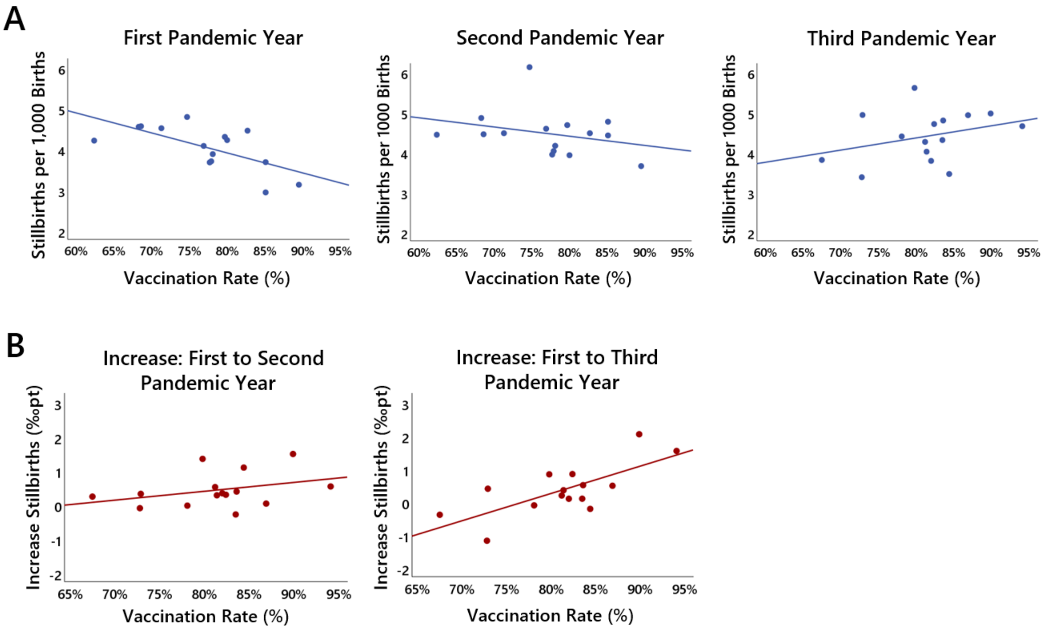

Figure 6: **Relationship between stillbirths and vaccination rates.** (A) shows the relationship between the vaccination rate in a federal state and the number of stillbirths per 1,000 total births is shown in the first (2020), second (2021), and third (2022) year during the pandemic. (B) shows the increase in stillbirths from the first to the second (from 2020 to 2021) and the third (from 2020 to 2022) year during the pandemic in pro mille points in the individual federal states as a function of the vaccination rate in a federal state.

In 2020, a negative correlation between the number of stillbirths and the vaccination rate in the subsequent year 2021 is observed ($r = -0.66$, $p = 0.007$). That is, in the federal states in which the stillbirth rate was lowest in 2020 before the vaccinations started, most people were vaccinated the following year 2021. The negative correlation decreases in the year 2021 where the vaccinations started ($r = -0.29$, $p = 0.290$) and turns around and becomes positive in 2022 ($r = 0.33$, $p = 0.234$).

As shown in Figure 6B, this is further supported by an analysis of the increase in the number of stillbirths from the first to the second (from 2020 to 2021) and the third (from 2020 to 2022) year during the pandemic. Already for the increase in the second year, a moderately strong positive correlation is observed ($r = 0.37$, $p = 0.178$), and in the third pandemic year, a strong positive correlation is observed ($r = 0.72$, $p = 0.002$), indicating that the increase in stillbirths was the higher the higher the vaccination rate. Note that the reported values refer to the federal states without the smallest federal state of Bremen, because Bremen was a strong outlier in in 2020 and 2022 (in both years stillbirth rate more than three standard deviations above the mean occur); including Bremen did not change the observed result pattern.

5 Conclusion

The present study used the state-of-the-art method of actuarial science to estimate excess mortality in the federal states of Germany in the three pandemic years (04/2020 to 03/2023). The estimated excess mortality showed substantially variance across the federal states. The exploration of several key state-specific quantities revealed that only two quantities showed a strong correlational relationship with the observed excess mortality: COVID-19 deaths and the COVID-19 vaccination rate. While the excess mortality in the first and second pandemic year was strongly correlated with the reported number of deaths and infections, in the second and third pandemic years, an increasingly stronger relationship between excess mortality and the vaccination rate was observed. Contrary to what would be expected with an effective vaccination, positive instead of negative correlations were observed: the more vaccinations were administered in a federal state, the greater the increase in excess mortality. This correlational finding is in line with previous correlational findings in the temporal domain, showing that excess mortality was highest during the months with a high number of vaccinations. The fact that particularly high excess mortality occurs both in regions and in time windows in which many vaccinations took place provide strong correlational evidence that the vaccinations may have had a negative effect instead of a positive effect. These findings support recent concerns about the COVID-vaccinations (Mead et al. [22]), and substantiate the suspicion that the negative side effects of the vaccination may possibly outweigh the positive effects.

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6 Supplement: Correlations between excess mortality in the pandemic years and the monthly vaccination rates.

The supplementary Figure 7 shows the correlations between the excess mortality observed in a federal state in the second and third pandemic year and the monthly rates of double and triple vaccinated people.

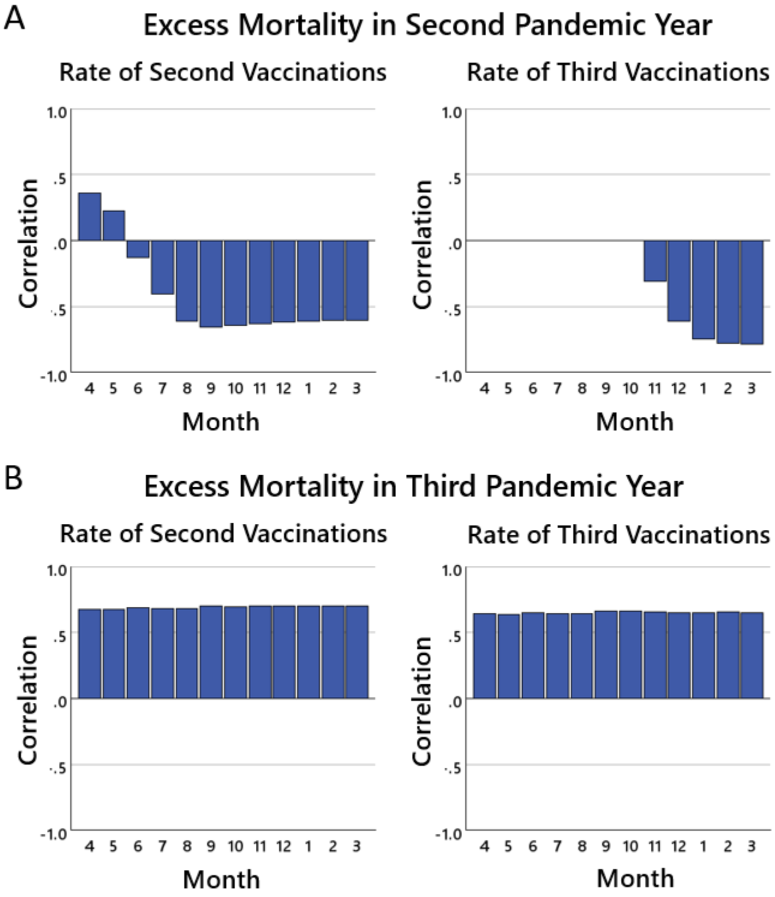

Figure 7: The correlations between the excess mortality in the second (A) and third (B) pandemic year and the monthly rates of double and triple vaccinated people are shown.

As can be seen, in the third pandemic year, the level of correlation is identical regardless on which month or type of vaccination (second vaccinations, third vaccinations) the vaccination rate of a federal state is based. In the second pandemic year, the same picture emerges as soon as the vaccination rates have reached relevant levels.

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